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A Subsidary of Chart Industries

The Truth About Vacuums

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Vacuum Overview

- Basics of Vacuum
- Vacuum Life Expectancy
- What Affects Vacuum?
- Extending Vacuum Life
- Experience & Analysis
- Restoring Vacuum in the Field
- Summary

Definition of Vacuum

Merriam-Webster Defines Vacuum as:

a) A space absolutely devoid of matter.

b) A space partially exhausted by artificial means (a pump).

<u>Cryogenic Insulation Requires (a).</u>

Vacuum Life Expectancy

Vacuum at Shipment is Less Than 5 Microns

- Perfect Vacuums are not Permanent
  - Expect 7-10 Years in N_2, O_2 & CO_2 Service.
  - Vacuum Levels Deteriorate Over Time.

  <u>This is Referred to as a "Soft" Vacuum.</u>
- What Causes a Vacuum to go "Soft"?
  - Air Molecules Enter the Space at Pump Out.
  - Other Molecules O*ut Gas* from the Materials.

Vacuum Trivia

• 1 ATM	760 mm Hg
• 1 ATM	760,000 Microns
• 1 PSI	51,714 Microns
• 1 Torr (1,000 Microns)	1 mm of Mercury
• 1” of Water	1866 Microns
• 1.0 cc-He/Sec	Audible leak
• .0001 cc-He/Sec	Smallest leak detected with a bubble test
• .000,01 cc-He/Sec	Smallest leak detected with a Freon tester
• .000,001 cc-He/Sec	Moisture plugs up a leak
• .000,000,001cc-He/Sec	Leak that we test for during Production

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What is *Out Gassing*?

- Molecules are Released into Vacuum Space
- Sources of Gas Molecules
  - Attached to the Surface of the Material
  - Dissolved in the Material During its Production
- Types of Materials
  - Stainless Steel Inner & Outer Vessels
  - Aluminum Foil & Paper Insulation
- Types of Gases
  - H_2O, O_2, N_2, H_2, CO, CO_2

More on *Out Gassing*

- Molecules are Released at Varying Rates
- Conditions that May Affect the Rate
  - Surface Finish of the Materials Used
  - Type & Quantities of Gases Present
  - Relative Pressures & Temperatures
- Conditions that May Affect Performance
  - Thermal Conductivity of the Gases

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Extending Vacuum Life

- Use of Adsorbents (Getters) in the Space
  - Catalysts are Used to Reform Molecules.
  - Chemical Sponges Absorb New Molecules.
- Cryo-Pumping Phenomenon
  - Cryogenic Temperatures Enhance Vacuum.
    - Shrinking Molecules in the Space.
    - Increased Capacity of Gettering System.

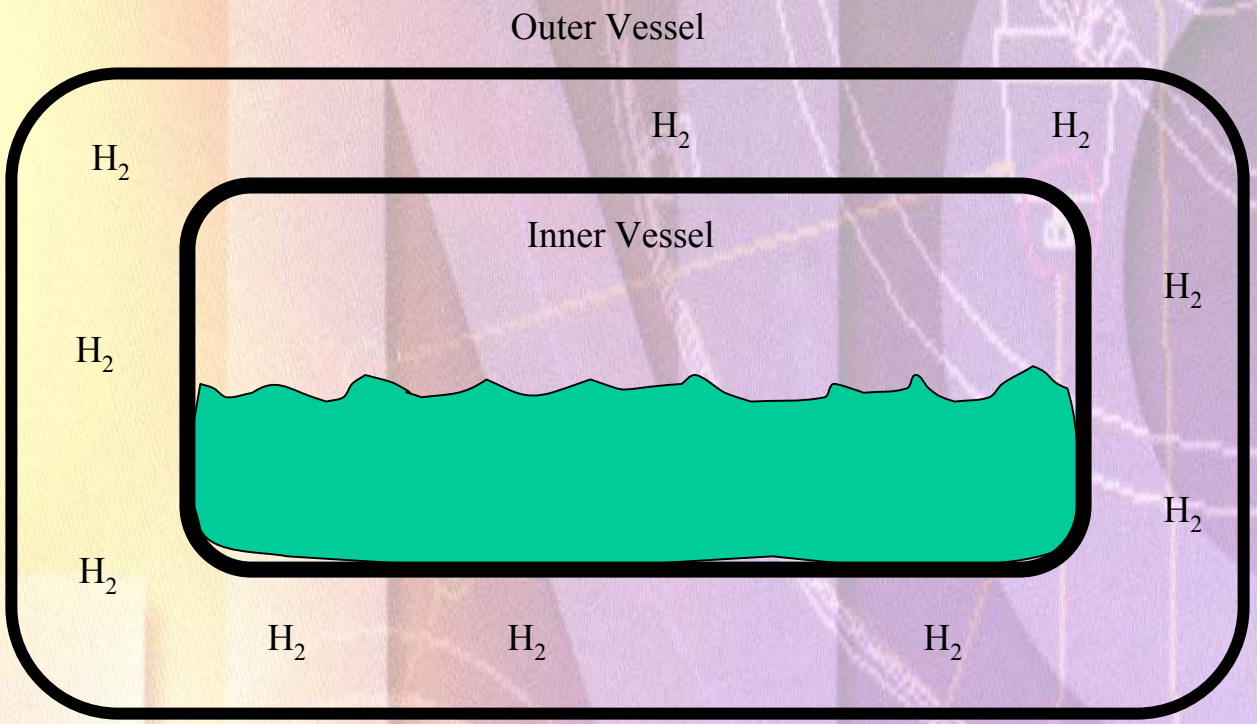
Field Experience on Problem Vehicles

- Exhibit Rapid Pressure Rise
- Vent Fuel to Atmosphere
  - Wastes Fuel
  - Safety Concerns
- 3 Causes of Rapid Pressure Rise
  - “Soft” Vacuum
  - Overfilling
  - Component Malfunction

Analysis of Returned Tanks

- Approx. 6,000 Units Shipped
  - 100 Units Returned for Evaluation
- Tanks Returned for Vacuum Issues
  - Only 70% Vacuum (200-500 Microns)
  - 20% Other (Cosmetic & Piping)
  - 10% Work Fine (Improper Diagnosis)
- Tanks With Vacuum Issues
  - 70% Excess H_2 Gas in Space
  - 20% Atmospheric Gas in Space
  - 10% Other

H_2 Molecules in Vacuum Space



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Why So Much H_2?

- Vehicle Service is Very Different
  - H_2 *Out Gassing* is Increased
    - Engine Heat & Direct Sunlight
    - Volume to Surface Area Ratio is Reduced
    - Long Periods of Non Use Before Filling
- CH_4 is Much Warmer than N_2 & O_2
  - Getter Capacity is Reduced
  - Effects of Cryo-Pumping are Minimal

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The Good News Is…..

The Tank Vacuum can be Easily Restored While the Tank is on the Vehicle in the Field

Restoring Vacuum

- Do Not Remove the Tank
- Do Keep the Vehicle in Service
- Confirm “Soft” Vacuum Condition
  - Perform Simple Diagnosis
  - See Field Service Bulletin
- Schedule Vehicle for Service
- Run the Vehicle to Consume Fuel
- Minimal Labor (approx. 4 Hrs.)

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Restoring Vacuum

1. Drain Any Residual Fuel
2. Warm Inner Tank to Ambient
3. Break Vacuum with N_2 Gas
4. Add Catalyst to Annular Space
5. Pump Vacuum Overnight
6. Seal Off at Less Than 5 Microns
7. Return to Normal Service

Equipment Required

- Field Purge Cart
  - Quickly Warms Tank to Ambient
  - Breaks Back Vacuum with N_2 Gas
  - Cost is Approx. $4,000.00
- Field Pump Cart
  - Oil Free High Efficiency Pump
  - Requires Std. 110V Outlet
  - Cost is Approx. $12,000.00

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Current Situation

- Chart is Handling All Valid Warranty Claims
- All Problem Units Serviced in Q1 2003.
- 12 Sets of Carts Have Been Deployed in the Field
  - ATC Phoenix/Tempe
  - Orange County Transit - Garden Grove/Anaheim
  - City/County of Sacramento
  - Waste Management in California
- Evaluating Logistics and Cost for Service
- Evaluating Changes in Warranty Policy

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Summary & Conclusions

- There are No Vacuum Leaks
- Vacuums are not Permanent
- LNG Tanks are Different from N_2 & O_2
- LNG Tanks Require Periodic Service
- Service Can be Performed On Site
- Budget 1 Service Every 3 Years
- Chart is Working to Extend Vacuum Life